FOOD PLANT DESIGN

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Contents

Summary

The design and construction of a new or expanded food plant involves the application of a few basic principles to address the following critical issues: a) minimization of capital and operating costs, while satisfying food safety regulations and quality expectations and b) performing the intended function, all within the agreed upon budget and schedule. The principles involved include: design for material flow, sanitation, and people, and careful choosing of a site. The means for applying these principles are the

tools of project management executed in phases, drawing upon the experience of qualified professionals.

1. Introduction

Design and construction of a new food manufacturing plant or factory is a rare event in most developed countries, and in the careers of most food professionals, because growth of overall food consumption is relatively slow in such places. However, in developing countries, as economies improve, food consumption in general, and that of processed or preserved food in particular, is growing, and thus the need for new food plants is especially important in such regions. This topic is intended to provide some of the general concepts required for a successful food plant design and to introduce in more detail certain critical aspects of such projects.

Food plant design, as used here, refers both to the physical facility, that is, the building and supporting utilities, and to the enclosed process equipment, because in reality, these cannot be easily separated. Unlike many other manufacturing situations, in which the building is merely an enclosure for the equipment and process, a food plant can be an integral part of the process and contributes significantly to its success or failure. While food scientists and engineers are heavily involved in food product and process development, building design typically falls to architects and structural engineers, few of whom have a deep understanding of food science. Thus, one objective of this piece is to enhance communication and understanding among disparate professions involved in the design and construction of facilities, which can significantly impact the health and welfare of many people.

Processed food, far from being a luxury, can significantly enhance an economy by releasing to the work force the skills and intelligence of people, mostly women, who are otherwise occupied by harvesting, preparing, and serving food. In addition to preserving perishable crops, thus retaining nutrients, ensuring safety, and reducing preparation time, processed foods can improve health, especially of children, increase incomes, reduce sickness, and improve the quality of life.

The breadth of the food processing industry is prodigious, which makes it difficult to generalize, but certain principles do apply. However, to understand the challenge, consider just a few significant segments of the industry:

- **Cereals**, such as wheat, corn, millet, and rice: typically milled into flour or meal, originally by hand, and on a progressively larger scale using waterpower, steam, and electricity. Perhaps the first industrial food process.
- **Meats,** such as beef, pork, and poultry: originally slaughtered individually, as needed, and later processed on a larger scale, requiring refrigeration and curing for preservation. Still very labor intensive, but more efficient than typical family farm processing.
- **Fruits and vegetables**: kept in cellars (refrigeration) with primitive drying, salting, or pickling until thermal processing and later, freezing, were discovered,. Frozen and canned in large quantities today for direct use and as ingredients in other foods.

- **Beverages**: beer, fruit and vegetable juices, wine, soft drinks, and milk have been and are important foods. In most Latin American countries, the largest food company is usually a brewer, who usually processes other foods as well. In ancient Egypt, beer was a staple food, a vehicle for using and preserving the nutrients of seasonal barley. In many countries today, it is an important and useful food.
- **Food ingredients**: an enormous category that includes salt, sugar, flavors, starches, colors, oils, vitamins, minerals, flavor enhancers, and numerous other materials used to preserve and improve processed foods. Manufacture of such ingredients is also a food process.
- **Dairy**: in addition to milk, a food directly derived from cattle, goats, sheep and horses, dairy foods such as cheeses, yogurt, cream and butter, have been and continue to be important in the diets of many cultures. Moving the manufacture of such from the camp or farm to a factory improves safety and consistency and makes the products more widely available, while opening up markets for the herder.

In light of the variety found in the food processing industry, it is necessary to consider the general principles that might apply across the potential range of application. As described in detail in the following sections, there are certain aspects that always apply:

- *Food Process Design.* This determines how the intended products in a plant are actually made. From this flow the material and people patterns, utility requirements, environmental conditions, and all other requirements to determine a facility design.
- *Food Process Simulation.* Once a process is devised, it is often simulated mathematically, and sometimes physically, to investigate parameters and determine operating conditions. The ability to simulate a process accurately is a good indication it is well understood, which is particularly comforting when installing a new or existing process at a new scale.
- *Process Instrumentation and Control.* It is always expected, even required legally, that food processes be under careful control, and well documented. The modern practice is to use computer automation to support Hazard Analysis and Critical Control Point (HACCP) programs and to integrate manufacturing with marketing, shipping, and logistics in as seamless a fashion as possible.
- *Food Plant Sanitation.* Sanitary design is an underlying principle of food plant design. Maintaining sanitary conditions is a constant challenge in operations, due to production requirements, low skill and motivation level of available labor, and inherent characteristics of foods and processing conditions.
- *Food Waste*. Food processing produces food waste, which typically is biodegradable, but can be in relatively high concentrations. Recovering values from food waste is always a high priority after a reduction in quantity, but ultimately, disposal is required for some amounts. Access to a convenient and economical means of disposal for liquid and solid food waste can be a factor in plant location.

2. Principles

2.1. Material Flow

The guiding principles in food plant design are the flow of material (primarily raw material), the work during process, and the finished goods. Flow of packaging materials and waste disposal are also important, as well as that of the people who normally move the material. The governing concept is to minimize the distance over which material is moved and to have some logic as to the direction and sequence of operations. There are three classic choices in overall plant layout:

- Straight-through
- "U" shaped (180°)
- "L" shaped (90°)

The straight-through pattern is the simplest and has the advantage of relatively simple expansion, by adding lines in parallel. To take advantage of this benefit, a plant design must provide space and not present obstacles to such expansion. For example, offices, labs, and locker rooms must be provided. It is best to position these together on a side that is not a candidate for expansion. One disadvantage is that shipping and receiving are at opposite ends of the building, requiring two clerks, two driver facilities (typically small), and two storage locations. Since it is usually wise to separate raw and finished goods in storage, such separation is not a serious defect.

The "U" shaped facility can have shipping and receiving on one side, but may find expansion more complex. Multiple lines must either fold back upon themselves or enclose others, both of which conditions can create complications. Such complications have been overcome.

The "L" shaped facility can adapt well to a less than ideal plot of land and can realize some of the benefits (as well as deficiencies) of the other patterns.

In every case, there are critical issues. What are the materials? How are they best handled? What trade-offs exist in cost, convenience, and flexibility? Are there other influences on the design?

Often the main processing equipment will dictate elements of the plant design. For example, baking ovens are up to 100 meters long and must be straight. Hydrostatic retorts are usually placed near outside walls to permit access for maintenance using cranes. Bakeries and mills rely on gravity to move grains, flour, and other solid ingredients, so are often constructed with multiple stories or towers, even at some increase in building cost as compared to single level designs.

Local building codes, customs, and environmental requirements will influence plant design. For example, in some countries, it is common to provide multiple hot meals to workers, thus requiring a full kitchen and dining area. In other countries, it may even be customary to provide sleeping quarters. Protecting neighbors against traffic, odors and other emissions may influence entry and exit roads, liquid and solid waste handling, and dust collection. A new food plant may need to treat its liquid waste, which may then require substantial additions of land and consideration of prevailing wind patterns. In many areas, a food plant may need to treat fresh water for processing and cleaning.

Even where potable water is of good quality, it often is treated before being used in beverages to remove sediment, flavor and color.

2.2. Sanitary Design

Foods are subject to many hazards, primarily contamination by microbes, foreign matter, and spoilage. Food plant design can protect against, but cannot guarantee against, such hazards. Most aspects of sanitary design are architectural details aimed at making plants easy to clean and less inclined to contaminate foods. These are irrelevant if the plant is not cleaned properly and frequently.

An overriding principle is based on basic biology, in that microbes need moisture to live. Therefore, if a plant's normal environment is dry, keep it dry. If the normal environment is wet, use wet methods to clean and sanitize. The difference is important. Once a dry area is made wet, it is normally difficult to make dry again. Typically, dry plants (e.g., flour mills), dried foods plants, and dry mixing plants have more sanitation problems with insects than with microbes, if they remain dry. In dry plants, the issues involve how to reduce dust, reduce dust accumulation, and conduct disinfection without leaving toxic residues from chemicals. One solution to the latter issue has been the heat treatment of plants, involving heating to 140 degrees F for up to 24 hours. This requires novel design of heating, ventilation, and air conditioning (HVAC) equipment, as well as careful specifications for all other equipment, which might be subjected to such conditions. Specifically, the HVAC system must be capable of reaching the required temperatures in a reasonable length of time (several hours), maintaining the temperature, and then cooling the facility. The equipment, especially the electronics, must be either capable of withstanding certain temperatures or be protected.

In a wet facility, the issues involve drainage, corrosion resistance, and avoidance of areas where soil can accumulate. All of these are directed at making it easy to clean the soil that could harbor microbes or become contaminants to foods. Wet areas may contain water, grease, blood, fat, syrups, and other materials on the floor. A good practice is to scoop or shovel the material, especially if it contains high solids, depositing it into tubs or bins for solid treatment or disposal. Such areas typically have hub or trench drains at a ratio of about one per 200 square feet, but this varies under circumstances. Trench drains can handle large quantities of water, but can also be difficult to clean and can harbor microbes, which are atomized into the atmosphere during cleaning. Properly sloped floors can present difficulties in setting equipment, and are difficult to build well.

Floor materials must withstand water and corrosive cleaning materials, such as caustic soda, as well as thermal shock from live steam, hot water, and hot oil. In addition, floors should not be too slippery (to avoid injury by slipping) but smooth enough to be well cleaned. Few materials meet all of these requirements. The historic food plant floor has been acid-proof brick with Furan grout, with the grout costing about the same as the brick. An epoxy resin coating over concrete with aggregate fillers has reduced costs and has had good performance, but thermal shock requirements must be specified carefully to define correct formulations.

All floor, wall, and ceiling joints must be smooth and designed to prevent accumulation of moisture or dirt. This may involve more expensive materials than otherwise might be used. For example, it is not good practice to use acoustic tile for the ceiling in a food plant. In fact, it is not recommended to have any ceiling in a food plant, if possible. The hidden side of the ceiling tends to become dirty and is a potential source of contamination. Good food plant design uses a precast roof structure in which case a ceiling is not needed.

Frequently, building utilities such as air handling units are placed on top of the roof, which means access to the roof is needed and that it must be stronger than usual. These are issues that are easily resolved early in a project, but which can be troublesome later.

Joints between vertical elements (e.g., columns or walls) and floors should be coved (i.e., rounded to prevent dirt accumulation). Columns should be encased in concrete with tapered tops. Structural elements should include simple angles or tubes, and the angles should be pointed down to avoid dirt accumulation. Uni-strut and all thread rods are never allowed in a food plant because of difficulty in cleaning and potential danger to workers from sharp edges.

Glass and wood are not recommended as construction materials because they pose a risk of contamination, and wood can be difficult to clean. Exceptions are made where wood is an economical building material, but it must be protected against water and the often harsh conditions of a food plant.
Painted surfaces are generally undesirable in a food plant because the paint can flake and contaminate food. Also, paint requires regular maintenance while smooth concrete surfaces do not.

2.3. Site Location

Food plant location may be dictated by either markets or raw materials, usually depending on the relative density of the products and raw materials. Additional influences are labor and utility costs, taxes, environmental regulations, and incentives offered by communities, states, and regions. A classic illustration of the influence of product density is with potato products. Dehydrated and frozen potato products, such as instant mashed potatoes and frozen French fries, are typically manufactured close to a potato growing region, such as Idaho or Washington in the United States. Potato chips, on the other hand, are typically produced near markets because of their relatively low bulk density and short shelf life. Fabricated potato chips, which have higher bulk density (because they nest) and longer shelf life (because of special packaging), are manufactured in large centrally located plants. Meatpacking is now typically located near cattle, hog, and poultry raising areas that tend to be rural. In the past, meatpacking was concentrated in transportation centers like Chicago, St. Louis, and Kansas City in the United States. Baking tends to be located near population centers, while milling tends to be near grain growing areas and transportation centers. Wineries are usually located near sources of grapes, while soft drink plants tend to be near markets.

In choosing a site for a new plant, an owner not only needs to examine the fundamental characteristics of the product and its raw materials, but also the other elements of its manufacture, such as other plants, distribution centers, research centers, corporate headquarters, and supporting suppliers. Suppliers might provide packaging materials and key ingredients, for example, cans or bottles or flour and pre-mixes. Different companies have different manufacturing strategies. For example, one company might elect to manufacture all of its main products in every facility, while another might have global centers specializing in only a few products.

Typically, distribution practices can influence plant location. Most food companies have multiple products and try to supply a full line of products to each customer. Rather than ship separately from multiple manufacturing locations, it is often more efficient to accumulate products in one location from which full orders can be assembled. This is a distribution center and can be a complex facility in its own right, with highly automated order picking and inventory control systems. If a company has multiple plants and distribution centers, then locating a new plant is influenced by transportation distances and costs, taking the system as a whole into account.

Often it is desirable to locate a distribution center with a manufacturing plant so that the transportation of the plant's output is minimal. Such a policy might also reduce the need for finished product storage within the plant, reducing construction costs and inventory. On the other hand, it might become necessary to receive trucks with products processed at other locations (or purchased from other sources). As distribution patterns evolve, with numerous customers operating their own centers, and others encouraging more direct-to-store delivery, finding the optimum location for a new plant becomes more difficult. The quality of available infrastructure, specifically roads and other transportation means, influences the size and location of a food plant. Where roads are poor, plants are typically small because of limits on the economic range of distribution. This can pose a challenge in design because trends in developed countries have been towards larger scale operations, so that equipment "small enough" may be difficult to find.

Underdeveloped areas in the United States and elsewhere compete strenuously for investment, which could generate jobs and tax revenues. Thus, a company contemplating construction of a new food plant could narrow its choices on the basis of its own economics, but make a final selection based on incentives offered by various communities. These could involve tax holidays, training of workers, desirable water or energy supply, waste treatment capacity, and other economic factors. Evaluation can be confusing, but ultimately these incentives have some influence on capital or operating costs and thus can be measured.

2.4. Design for People

The above-mentioned principles determine the "hard" aspects of a food plant design: where it is located, how it generally looks, and most of the construction details. Equally important are the "softer" aspects. What sort of place is it in which to work and what sort of neighbor is it? Food processing can be a dangerous and unpleasant task. Some food industries (e.g., meat packing) are statistically more dangerous in which to work than is the mining industry. Typically, employees must work close together. Often, they must lift heavy weights and perform repetitive motions, use sharp tools, work around hot oil and steam, and work in a cooled and high humidity environment. Other plants may be dusty or very warm and humid.

Some of these conditions are unavoidable, but efforts should be made to reduce sources of discomfort and injury. For example, mechanical assistance should be provided when moving more than forty pounds vertically. Ventilation and air conditioning can be provided to reduce hostile environments, or relief locations provided, such as warming rooms for those working in freezers. Control of hoses, repair of leaks, and properly drained floors can reduce slipping hazards and improve sanitary conditions. Allowing adequate space for safe access to machinery contributes to safety and reliable operation, because equipment can then be inspected and repaired more easily.

If a good design is invoked from the beginning, a food plant can be an attractive building and a source of pride to employees and the community. This could include attractive landscaping, disguising of firewater ponds, and highlighting of significant elements in the design. For example, one plant placed its quality control laboratory near the entrance to emphasize the importance of quality, using interesting curtain walls as a design feature. Another made its mundane shipping and receiving office into an attractive interruption of an otherwise plain concrete wall. Still another plant used various colors for insulated panels to emphasize and define functional elements of the building. This was especially clever, as it entailed no cost premium over the usual white color of such panels, but converted a potentially boring mass into an articulated and interesting sculpture. No matter how it is accomplished, it is important that a food plant be designed as both a safe place to work and an interesting place to see.

It is not sufficient that a food plant should simply obey regulations and look attractive to be a good neighbor in the community. It must not be a nuisance. Odors in particular are a potential source of annoyance as is noise. Heavy truck traffic and employee vehicles may disrupt a neighborhood. Accumulations of food waste may attract rodents and birds. Proper attention to these issues in design and operation will make a food plant less intrusive. Observation of immediate neighbors is also important. For example, it would be undesirable for a food plant to be downwind of a plant emitting noxious fumes or dusts that could contaminate foods. A landfill attractive to pests would not be a desirable neighbor. Thus, a food plant interacts with the community by contributing to its environment and by receiving from it. Properly designed and operated, a food plant can be a constructive and appreciated addition to the community, bringing jobs, tax revenue, and local pride.

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Biographical Sketch

J. Peter Clark is a consultant to the process industries in Oak Park, IL. Previously, he was vice President of Technology with Fluor Daniel, Inc. in Chicago; Senior Vice President of Process Technology and President of Epstein Process Engineering with A. Epstein and Sons International, Inc. in Chicago; Director of Research and Development for ITT Continental Baking Company in Rye, NY; Associate Professor of Chemical Engineering at Virginia Tech in Blacksburg, VA; and Research Engineer with the U. S. Agricultural Research Service in Berkeley, CA and Washington, DC. He earned his BSChE from the University of Notre Dame and his Ph.D. from the University of California, Berkeley. He has written over forty papers on food engineering and food plant design, co-authored five books, and has one patent. He is a Fellow of the American Institute of Chemical Engineers and received the Annual Award from the Food, Pharmaceutical and Bioengineering Division. He is a member of the Institute of Food Technologists, the American Association of Candy Technologists, and the American Association of Cereal Chemists. He is a registered professional engineer in Virginia and Illinois.